MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2018/19

ENT3036 – SEMICONDUCTOR DEVICES
(NE)

14 MAR 2019
9.00 am – 11.00 am
(2 Hours)

INSTRUCTION TO STUDENTS

1. This Question paper consists of 6 pages with 4 Questions only.
2. Answer all the questions and all the questions carry equal marks of 25. The distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.

Question 1

(a) A p^+n silicon junction diode is doped with $N_a = 10^{18}$ cm^{-3} and $N_d = 10^{16}$ cm^{-3}. The minority carrier hole diffusion length L_p = 11.1 μm and minority carrier hole diffusion coefficient D_p = 12 cm^2/sec. The junction area is $A = 10^{-4}$ cm^2. Calculate the reverse saturation current and the forward-bias current for V_A = 0.5 V. Sketch and label the results onto a current versus voltage graph of the diode.

$$(J_S = \frac{eD_p p_{n0}}{L_p} + \frac{eD_n n_{p0}}{L_n})$$

[5+2 marks]

(b) Draw the band diagrams of a npn BJT under zero bias and under forward active mode bias. [3 marks]

(c) A silicon npn bipolar transistor (Fig. Q1) is uniformly doped and biased in the forward active region. The B-C junction reverse biased by 4 volts. The metallurgical base width is 1.10 μm. The transistor doping are $N_E = 5 \times 10^{17}$ cm^{-3}, $N_B = 5 \times 10^{16}$ cm^{-3} and $N_C = 5 \times 10^{15}$ cm^{-3}.

$$x_n = \left[\frac{2\varepsilon_S(V_{bi}+V_R)}{e}\left(\frac{N_a}{N_d}\right)\left(\frac{1}{N_a+N_d}\right)\right]^{1/2} \text{ and } x_p = \left[\frac{2\varepsilon_S(V_{bi}+V_R)}{e}\left(\frac{N_d}{N_a}\right)\left(\frac{1}{N_a+N_d}\right)\right]^{1/2}$$

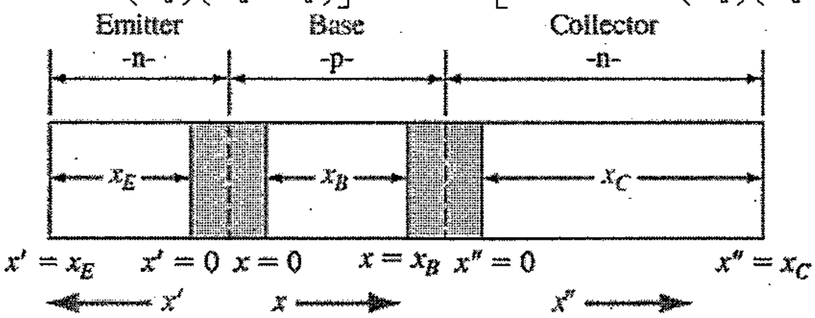

Figure Q1

(i) For T = 300 K, calculate the B-E voltage at which the minority carrier concentration at x = 0 is 10 percent of the majority carrier hole concentration.

(ii) At this bias, determine the minority carrier hole concentration at $x' = 0$.

(iii) Find the width x_p at the B-C space charge region and determine the neutral base width for this bias if x_p at the B-E junction is 0.053 μm.

(iv) Sketch and label the diagram of minority carrier distribution of the BJT.

[4+3+5+3 marks]

Continued ...

Question 2

(a) State two main differences of BJT and FET [2 marks]

(b) By means of a diagram of a n-channel JFET and the ideal current voltage characteristics at different V_{GS} (label the saturation and non-saturation region in the graph), explain the operation of the JFET and the pinchoff effect at different V_{GS}.
[5+5 marks]

(c) Consider an n^+p junction of a silicon JFET at T = 300 K with impurity doping concentrations of $N_a = 10^{16} cm^{-3}$ and $N_d = 10^{18} cm^{-3}$. The channel thickness is 0.4 μm. Find the internal pinchoff voltage (V_{po}) and the pinchoff voltage (V_p).

$$V_{po} = \frac{ea^2 N_x}{2\epsilon_s}$$

where a is the channel thickness and N_x is the doping concentration of the channel.
[4 marks]

(d) Briefly define the followings for JFET:
(i) Transconductance
(ii) The maximum operating frequency (f_T)
(iii) Velocity saturation effects
(iv) Channel length modulation
(v) Substhreshold and gate current effects

[5 × 1 marks]

(e) Briefly describe MESFET and its advantages as compared to JFET.
[2 + 2 marks]

Continued...

Question 3

(a) Explain the accumulation, depletion and inversion of metal oxide semiconductor (MOS) capacitors with p-type substrate with the aid of energy-band diagrams at
(i) zero gate bias,
(ii) a negative gate bias
(iii) a moderate positive gate bias
(iv) a large positive gate bias [10 marks]

(c) Draw the characteristic capacitance versus gate voltage curves of an MOS capacitor with p-type substrate. Label the followings:
(i) the region corresponds to accumulation, depletion, moderate inversion and strong inversion respectively.
(ii) C_{ox}, C_{sd}, C_{min},
(iii) V_{FB}, V_T [5 marks]

(c) A MOS device with an aluminum gate ($\phi_{ms} \cong -0.94\,\text{V}$) is fabricated on a p-type Si substrate with doping concentration 4×10^{16} cm^{-2}. The silicon dioxide thickness t_{ox} = 22 nm, and the trapped oxide charge $Q'_{ss} = 4 \times 10^{10}$ electronic charges per cm.
(i) Calculate C_{ox} and Q'_{ss}.
(ii) Given x_{dT} (the maximum space charge width) is 1.575×10^{-5} cm, calculate ϕ_{fp} (the potential between E_{Fi} and E_{Fp}), Q'_{SD}(max) (the maximum space charge in the depletion region) and obtain the threshold voltage V_{TN}.
[2 + 5 marks]

(d) An ideal n-channel MOSFET is operated with the following parameters: channel width to length ratio W/L =12, electron mobility μ_n = 650 cm^2/V-s, $C_{ox} = 4.3 \times 10^{-7}$ F/cm^2 and threshold voltage V_T = 0.40 V. If the transistor is biased in the saturation region, calculate the drain current for V_{GS} = 1.2 V.
How will the saturation current change when V_{GS} increased? [2+1 marks]

Continued ...

Question 4

(a) (i) With the aid of band diagram and a graph of current density versus electric field, explain "negative differential resistance". [8 marks]

(ii) Sketch the current-voltage curve of Gunn diode. Label the threshold voltage, the maximum operating voltage and the oscillation region. [4 marks]

(b) (i) A n-GaAs Gunn diode with drift region length of 15 μm is oscillating between 8 and 10 V; find the average electron drift velocity from Fig. Q4 and determine the frequency of oscillation. [5 marks]

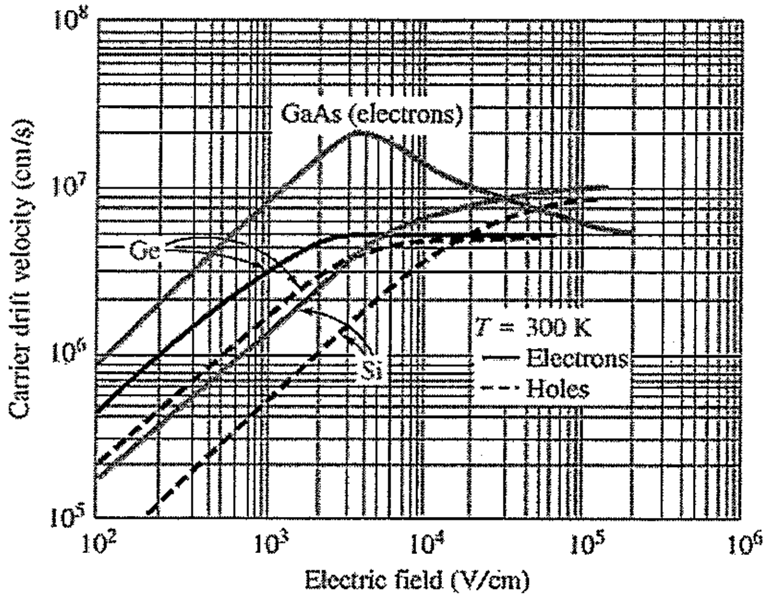

Fig. Q4 Carrier drift velocity versus electric field for Si, Ge and GaAs.

(c) (i) Sketch the structure of an Ionization Avalanche Transit-Time (IMPATT) diode and oscillator circuit required for its operation. [4 marks]

(ii) An Si IMPATT diode has a drift region length of 15.0 μm and the holes drift velocity is shown in Fig. Q4. Calculate the optimum operating frequency for the diode. [4 marks]

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PHYSICAL CONSTANTS:

Thermal voltage:	$V_t = 0.0259$ V
Intrinsic concentration of Silicon at 300K:	$n_i = 1.5\times10^{10}$ cm^{-3}
Intrinsic concentration of Silicon at 373K:	$n_i = 2.5\times10^{12}$ cm^{-3}
Intrinsic concentration of Gallium Arsenide at 300K:	$n_i = 1.8\times10^{6}$ cm^{-3}
Boltzmann's constant:	$k = 1.3806\times10^{-23}$ J/K
Electronic charge:	$e = 1.6\times10^{-19}$ C
Permittivity of free space:	$\varepsilon_0 = 8.85\times10^{-14}$ F/cm
Dielectric constant of Silicon at 300K:	$\varepsilon_r = 11.7$
Dielectric constant of Silicon oxide at 300K:	$\varepsilon_i = 3.9$
Dielectric constant of Gallium Arsenide at 300K:	$\varepsilon_{GaAs} = 13.1$

End of paper.